CHAPTER 1
INTRODUCTION

1-1. Purpose and scope.

a. This manual provides criteria and guidance for design of foundations for structures for military facilities in arctic and subarctic regions.

b. To facilitate the use of this manual, superscript numbers are used to refer to Appendix A-References. These references have been divided into publications required to use the manual (Required Publications) and additional related publications (Related Publications.)

1-2. Environmental conditions in the Arctic and Subarctic.

The design, construction and maintenance of foundations are all affected by the special environmental conditions found in the Arctic and Subarctic [109, 110]. (Superscript numbers indicate references listed in app A.) These conditions typically include the following, as applicable:

Seasonal freezing and thawing of ground with attendant frost heaving and other effects.
Occurrence of permanently frozen ground subject to thawing and subsidence during and following construction.
Special physical behavior and properties of frozen soil, rock, and construction materials at low temperatures and under freeze-thaw action.
Difficulty of excavating and handling frozen ground.
Poor drainage and possible excess of water during thaw caused by the presence of impervious frozen ground at shallow depths.
Thermal stresses and cracking.
Ice uplift and thrust action.
Limited availability of natural construction materials, support facilities, and labor.
Adverse conditions of temperature, wind, precipitation, distance, accessibility, working seasons, and cost.

While these factors are important in many other types of construction such as pavements[6] and utilities[3], they merit separate consideration for foundations for structures.

a. Temperature. The single most important factor contributing to the existence of these adverse conditions in the northern regions is the prevailing low air temperatures, demonstrated not only in the intensity and duration of cold in winter itself but also in the low mean annual temperatures.

(1) In general, mean annual temperatures decrease with increasing latitude or elevation, and the amplitude of the annual air temperature cycle generally decreases as large bodies of water or oceans are approached. Under natural conditions, mean annual ground temperatures are usually 2 °F to 5 °F higher than mean annual air temperatures, though deviations are sometimes outside this range. The difference between air and ground temperatures is attributable primarily to additional heat input from absorption of solar radiation at the ground surface in the summer, to restriction of heat loss by the insulating effect of a snow cover during the winter months, and to the normal temperature difference which occurs in heat flow across a solid/gas interface. Mean annual air temperatures in the Northern Hemisphere are shown in TM 5-852-1'°.

(2) Air temperatures in arctic environments may range from highs of 75 °F to 85 °F in the summer to lows of -50°F to -75 °F during the coldest winter months. It is not uncommon for air temperatures to remain below -30°F for a week or more at many locations in Alaska and in fact air temperatures have remained below -50°F for as much as several weeks. A typical record of air temperatures for a one-year period at Fort Yukon is shown in figure 1-1, along with other data, including ground temperatures.

b. Front conditions.

(1). Seasonal frost areas are those areas where significant freezing occurs during the winter season but without development of permafrost. In North America significant seasonal frost occurs about I year in 10 in northern Texas. A little farther to the north it is experienced every year. As indicated in figure 1-2, depth of seasonal freezing increases northward with decreasing mean annual air temperature until permafrost is encountered. With still further decrease of mean annual temperature, the zone subject to annual freezing and thawing becomes progressively thinner [164]

(2) Permafrost areas[174] are those in which perennially frozen ground is found. In North America permafrost is found principally north of latitudes 55° to 65°, although patches of permafrost are found much farther south on mountains where the temperature conditions are sufficiently low, including some mountains in the United States. The depth to the surface of permafrost is dependent primarily on the magnitude of the air thawing index, the radiational input to the surface (as controlled by such factors as latitude, amount of cloudiness, degree of shading or exposure, vegetation, and surface color), and the water content and dry unit weight of the soil.

(*a*) *In zones of continuous permafrost, frozen*

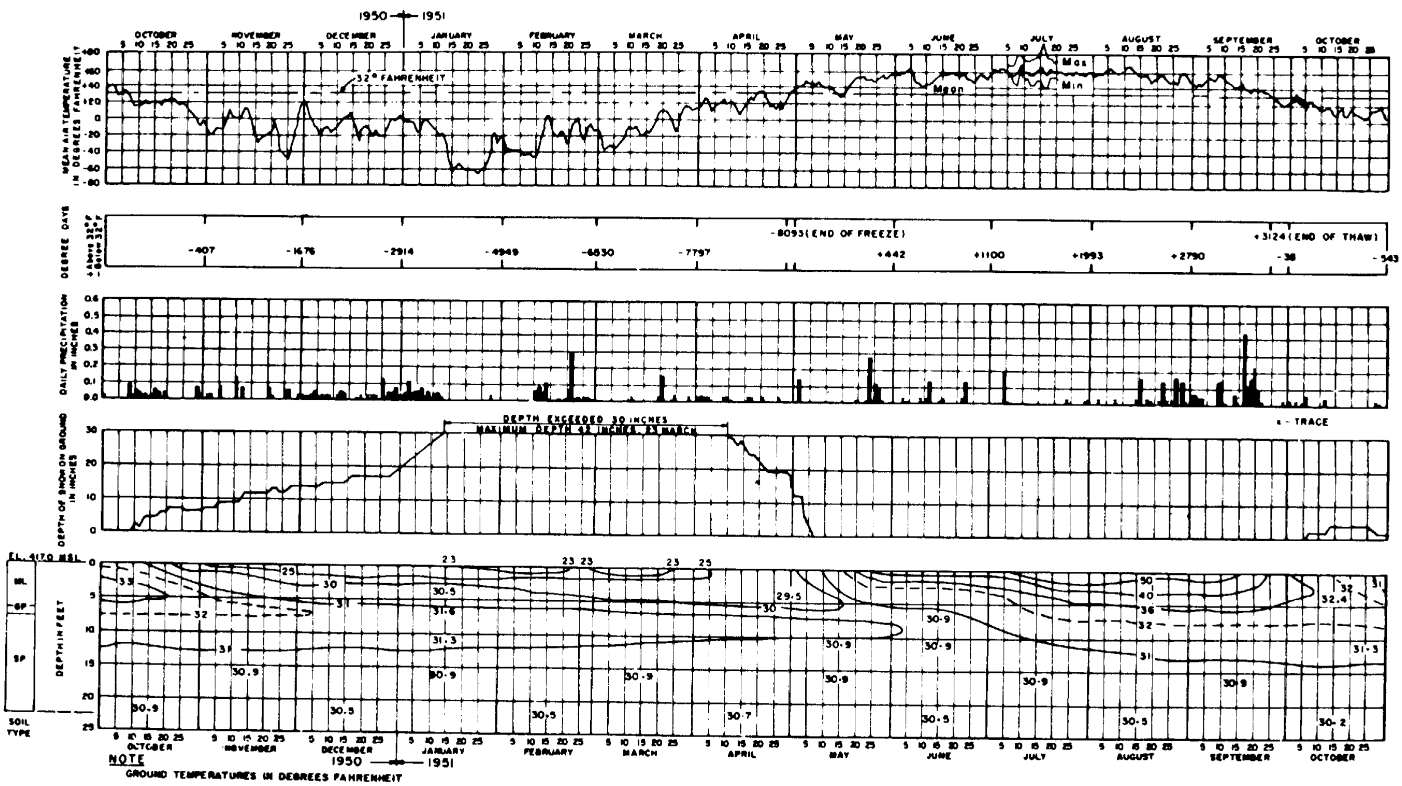

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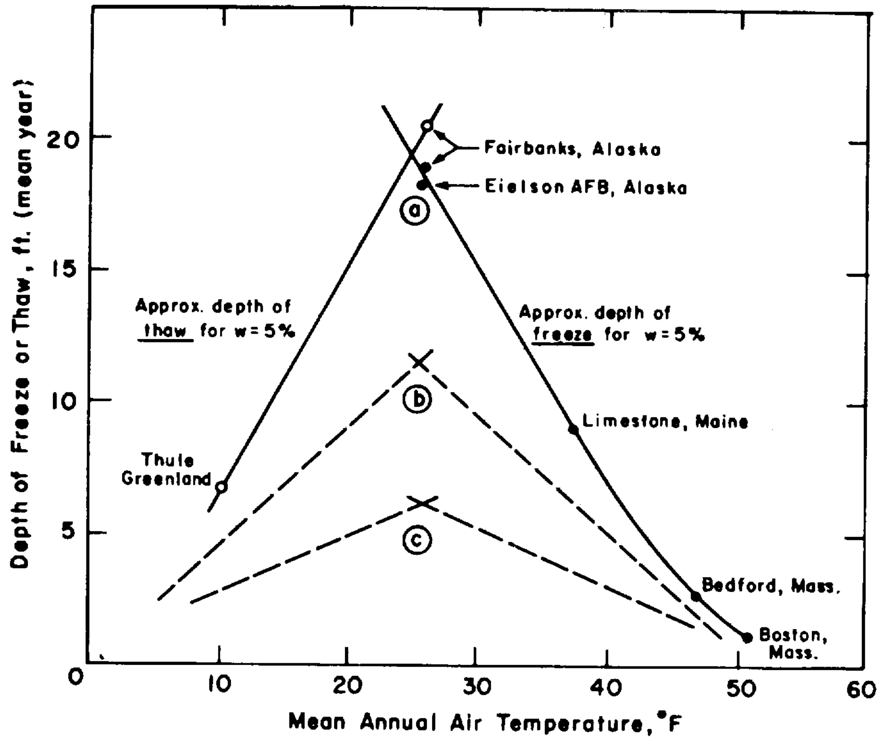
Figure 1-1. Meteorological data and ground isotherms, Fort Yukon, Alaska[99]



(a) For bituminous paved areas over well drained grovel, kept clear of snow.
(b) a (c) Typical for other soil, moisture and surface conditions.

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Figure 1-2. Freeze or thaw penetration vs mean annual temperature [164].

ground is absent only at a few widely scattered locations, as at the bottom of lakes and rivers.

(b) In zones of discontinuous permafrost, permafrost is found intermittently in various degrees. There may be discontinuities in both horizontal and vertical extents.

(c) The boundaries between zones of continuous permafrost, discontinuous permafrost, and seasonal frost without permafrost are poorly defined. Distinctions between continuous and discontinuous permafrost, in particular, are somewhat arbitrary.

(d) Definitions of specialized terms, more detailed discussions on seasonal frost and permafrost, and the approximate extent of continuous and discontinuous permafrost in the Northern Hemisphere are given in TM 5-852-1 0 general provisions.

c. Thermal regime in the ground. As shown in figure 1-3, temperatures below the ground surface vary with the seasons. The annual ground temperature fluctuation decreases in amplitude with depth and lags in time behind the air temperature variations occurring at the surface [197]. The decrease of annual amplitude with depth is illustrated in a more general way in figure 1-4. Below a depth in the range of 30 to 60 feet, the amplitude of annual temperature variation becomes small and the temperature gradient corresponding to the normal flow of heat outward from the interior of the earth becomes discernible. When the ground temperature curve with depth at its warmest extreme is below freezing over a portion of its length, as in figure 1-4, a permafrost condition exists. When the curve shows ground temperatures entirely above freezing at its warmest extreme, but freezing does occur at its coldest extreme, only seasonal frost conditions exist. A seasonal freeze and thaw zone, called the "annual frost zone," occurs even in the permafrost areas, except at very extreme locations where the air temperatures remain well below freezing even in the summer. The annual frost zone is usually not more than 10 feet thick, but it may exceed 20 feet.

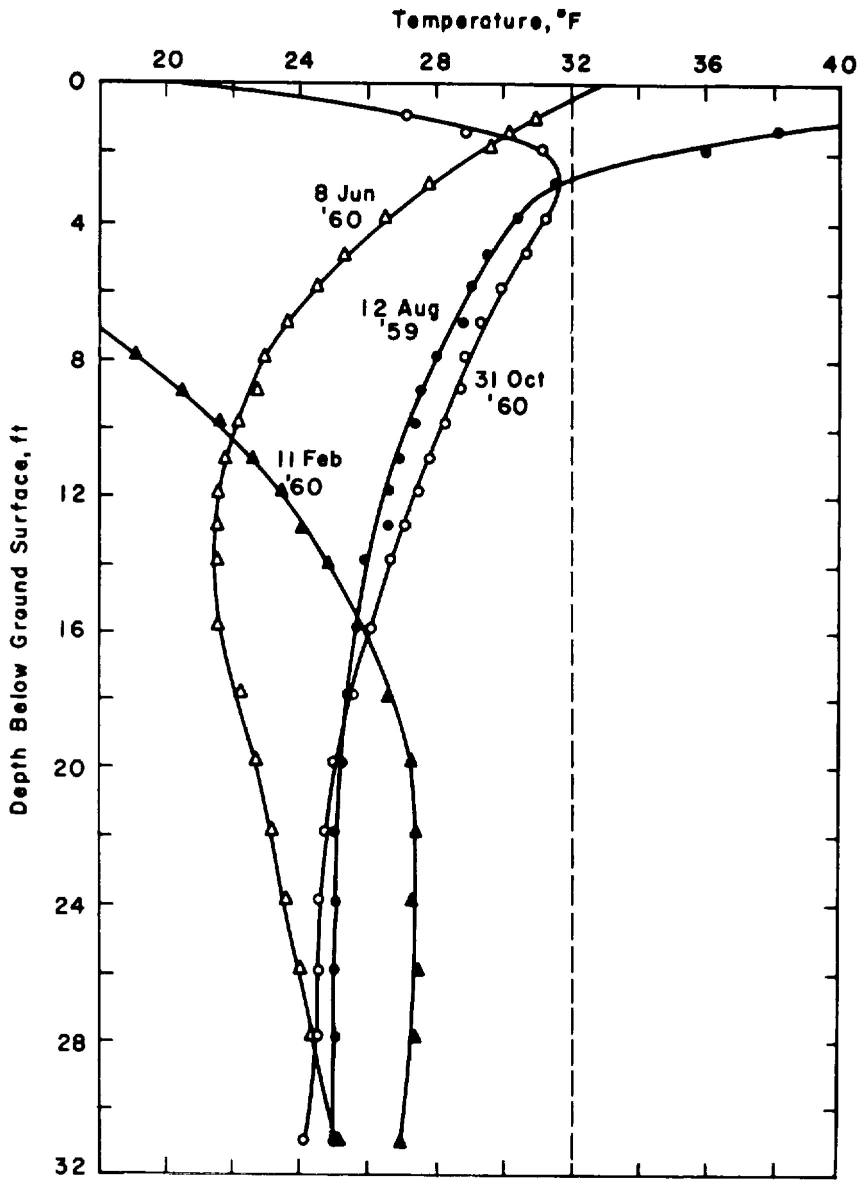

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Figure 1-3. Typical temperature gradients under permafrost conditions, Kotzebue Air Force Station, Alaska.

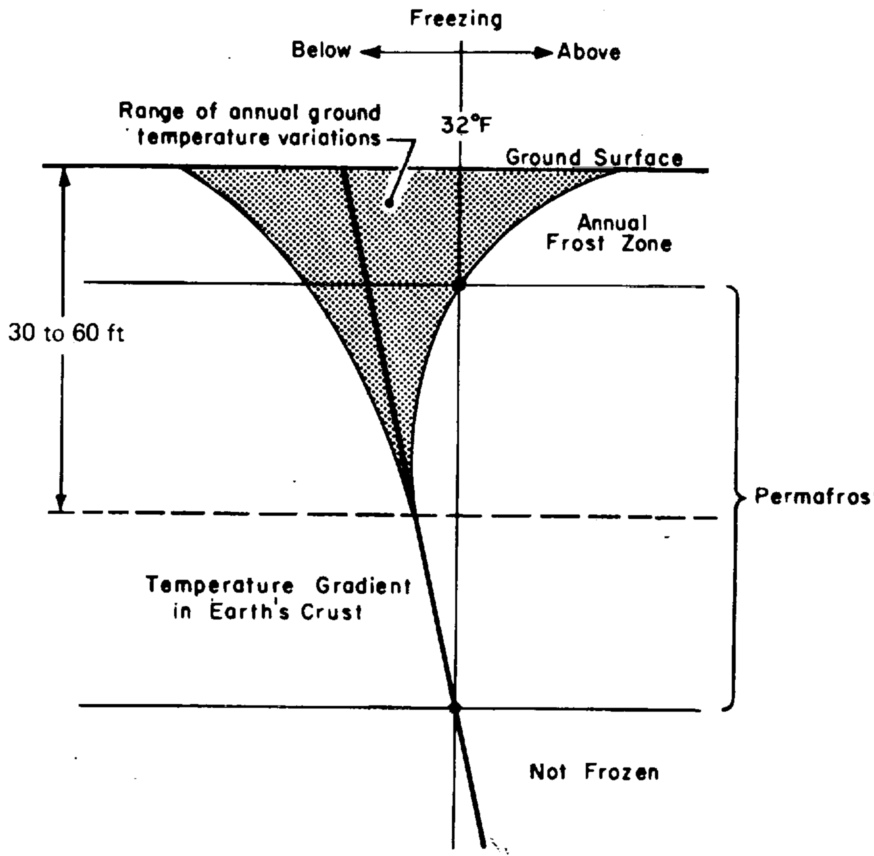

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Figure 1-4. Typical temperature gradients in the ground.

Under conditions of natural cover in very cold areas, its thickness may be as little as 1 foot or less; thickness may vary over a wide range even in a relatively limited geographical area.

(1) Seasonal variations in properties and behavior of foundation materials are caused primarily by the freezing, thawing, and redistribution of water contained in the ground and by the variations of stress-strain characteristics and thermal properties with temperature. The water may be present in the voids before freezing or may be drawn to the freezing plane during the freezing process and released during thawing. Seasonal changes are also produced by shrinkage and expansion caused by temperature changes.

(2) Below the zone of seasonal effects the temperature gradient usually averages 1 °F for 40 to 50 feet of depth, although it may range from about 1 °F in 15 ft to 1 °F in 135 feet. Since foundation work rarely extends below a depth of about 30 feet, most foundation design is concerned with the environmental effects encountered in the upper 30 ft.

(3) The penetration of freezing temperatures into the ground depends upon such factors as weather, radiation, surface conditions, insulating or other special courses, soil properties and soil moisture.[43, 83, 181, 185] The most important weather conditions are air temperatures and length of freezing season. These may be combined into indices, based upon accumulated degree-days as explained in TM 5-852-1/AFM 88-19, Chapter 1 [10].

(4) It is important to note that the indices found from weather records are for the air about 4-1/2 feet above ground. The value at the ground surface, which determines frost effects is usually different, being generally higher for thawing and lower for freezing, and is the composite result of many influencing variables, some of which have been mentioned in (3) above. The *surface index*, which is the index determined for temperatures immediately below the surface, is n times the air index, where n is the *correction factor*. For paved surfaces kept cleared of snow and ice, n may usually be taken as 0.7 for freezing. Other values are give in chapter 2. Turf, moss, other vegetative cover and snow cover with reduce the n value for temperatures at the soil surface in relation to air temperatures, and hence frost penetration will be less for the same air freezing index.

(5) TM 5-852-1/AFM 88-19, Chapter 1 [10] gives the approximate distribution of mean air-freezing and air-thawing intensities in North America. More detailed information for northern Canada is given by Thompson. [199] As demonstrated by Gilman,[64] highly useful summaries for local areas can be prepared when sufficient weather data are available. Calculation methods for determining the freezing and thawing conditions which may be anticipated for specific situations, more detailed explanation of the factors influencing freeze an thaw penetration, and typical values of n are presented in TM 5-852-6/AFM 88-19, Chapter 6 [14].

(6) Because temperature inversions and steep temperature gradients are common in levels of the atmosphere nearest-the ground, temperature differentials of as must as 50°F may be found at a given time at different local topographical positions. Within the range of ground elevations subject to temperature inversions, mean temperatures may actually increase rather than decrease with increasing elevation. For such reasons, it is important to determine design indices for the specific site topographic position.

(7) Anything which is done in the course of construction is likely to alter the temperature conditions at the surface of the ground and, as a consequence, to change the thickness of the annual frost zone and the depth to the top of permafrost, and ultimately, possible even to affect the existence of the permafrost.

d. Wind and other factors. Mean annual wind speeds for most arctic and subarctic locations are usually of the order of 5 to 10 mph except in coastal areas where the mean is usually 10 to 20 mph. In mountainous regions wind speeds are generally greater than those in the plains. Local katabatic winds with velocities up to 100 mph or more are not uncommon, particularly along sea coasts. Even though velocities of arctic winds as a whole tend to be low, combination of very cold temperatures with wind causes extremely large heat losses from buildings, equipment, and personnel in winter. Wind chill values representing the combined effects of wind and temperature are given in TM 5-852-1/AFM 88-19, Chapter 1 '°. Table 1-1 relates wind chill values to human working conditions. Drifting and blowing of snow often creates major construction and operational problems, even where the actual precipitation is very low. It is of fundamental importance to anticipate such problems in planning and design stages. It is often possible to reduce greatly adverse effects of drifting and blowing snow by proper site selection and layout alone.

e. Solar radiation. As previously indicated, solar radiation is an important factor in the thermal stability of foundations in arctic and subarctic areas. Net summer radiational input into the ground may range from almost nothing in very cloudy or shaded locations to a predominant part of the summer heat flow at others. It is a function of latitude, cloud cover, time of year, time of day, atmospheric conditions, wind speed, subsurface thermal properties, degree of shading, if any, and aspect, albedo and roughness characteristics of the surface [88].

Table 1-1. Stages of Relative Human Comfort and the Environmental Effects of Atmospheric Cooling.

Effects of Atmospheric Cooling.

Wind chill factor (kg cal/m^2 hr)	Relative comfort
600	Conditions considered as comfortable when men are dressed in wool underwear, socks, mitts, ski boots, ski headband, and thin cotton windbreaker suits, and while skiing over snow at about 3 mph (metabolic output about 200 kg cal/m^2 hr).
1000	Pleasant conditions for travel cease on foggy and overcast days.
1200	Pleasant conditions for travel cease on clear sunlit days.
1400	Freezing of human flesh begins, depending upon the degree of activity, the amount of solar radiation, and the character of the skin and circulation.
1600	Travel and life in temporary shelter very disagreeable.
1900	Conditions reached in the darkness of mid-winter. Exposed areas of face freeze within less than a minute for the average individual. Travel dangerous.
2300	Exposed areas of the face freeze within less than 1/2 minute for the average individual.